ARR June 1941

APR 10 1947

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
June 1941 as
Advance Restricted Report

WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS

I - EFFECT OF GAP ON THE AERODYNAMIC CHARACTERISTICS OF AN

NACA 0009 AIRFOIL WITH A 30-PERCENT-CHORD PLAIN FLAP

By Richard I. Sears

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

FOR REFERENCE

NOT TO BE TAKEN FROM THIS ROOM

NACA

WASHINGTON

NACA WARTIME REPORTS are reprints of papers originally issued to provide rapid distribution of advance research results to an authorized group requiring them for the war effort. They were previously held under a security status but are now unclassified. Some of these reports were not technically edited. All have been reproduced without change in order to expedite general distribution.

L - 377

NASA Technical Library
3 1176 01403 4640

L-377

WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS

I - EFFECT OF GAP ON THE AERODYNAMIC CHARACTERISTICS OF AN NACA 0009 AIRFOIL WITH A 30-PERCENT-CHORD PLAIN FLAP

By Richard I. Sears

SUMMARY

Tests have been made to determine the effect of a gap at the flap nose upon the aerodynamic section characteristics of an NACA 0009 airfoil with a plain flap and tab. The results are presented in the form of airfoil and flap section characteristics for several flap deflections, tab deflections, and for four sizes of gap.

The results showed that a plain flap with a sealed gap was best because it gave maximum effectiveness with minimum stick forces and because it was the most effective in delaying separation over the flap surface.

INTRODUCTION

Because of the increasing size and speed of modern airplanes, it has become increasingly important to reduce hinge moments on the controls and thus to reduce the forces on the control stick. In an effort to solve this problem, the NACA has initiated an extensive investigation of the aerodynamic characteristics of control surfaces to provide data for design purposes and to determine the type of flap arrangement best suited for use as a control surface. Because a conventional control surface is merely a flap on an airfoil, these two terms are used synonymously in this paper. As a part of this investigation, the effects of flap-nose shape and gaps on a typical horizontal tail of finite span were determined in the full-scale wind tunnel and are reported in reference 1. The more fundamental part of the investigation is, however, being made in two-dimensional flow. The first

part of the two-dimensional-flow investigation was the determination of the section characteristics for airfoil-flap combinations with plain flaps of various size and with sealed gaps. (See references 2, 3, and 4.) The data presented in references 2, 3, and 4 have been analyzed, and parameters for determining the characteristics of a thin symmetrical airfoil with a plain flap of any chord and with the gap at the flap nose sealed are given in reference 5.

The tests herein reported were made to provide section data for an airfoil having a plain flap with various gaps at the flap nose. This paper has been prepared to make the test results immediately available without too detailed an analysis.

APPARATUS AND MODEL

The tests were made in the NACA 4- by 6-foot vertical tunnel (reference 6) modified, as described in reference 2, for force tests of models in a two-dimensional flow. A three-component balance system has been installed in the tunnel in order that force-test measurements of lift, drag, and pitching moment may be made. The hinge moments of the flap and the tab were measured with special torque-rod balances built into the model.

The 2- by 4-foot model (fig. 1) was made of laminated mahogany to the NACA 0009 profile. It was equipped with a plain flap having a chord 30 percent of the airfoil chord and a plain tab having a chord 20 percent of the flap chord. The nose radii of the flap and the tab were approximately one-half the airfoil thickness at the respective hinge axes. The flap gap was varied by providing the model with removable airfoil tail blocks. The tab was made of brass and its gap was fixed at 0.1 of 1 percent of the airfoil chord.

The installation of the model in the tunnel was similar to that of references 2 and 7. Because the model completely spanned the tunnel, two-dimensional flow was approximated. Flap and tab deflections were set by friction clamps on the torque rods that were used in measuring the hinge moments.

L-377

TESTS

The tests were made at a dynamic pressure of 15 pounds per square foot, which corresponds to an air velocity of about 76 miles per hour at standard sea-level conditions. The effective Reynolds number of the tests was approximately 2,760,000. (Effective Reynolds number = tunnel Reynolds number × turbulence factor. The turbulence factor for the 4- by 6-ft vertical tunnel is 1.93.)

The flap was set at deflections from 0° to 30° in 5° increments. The tab was set at 0°, 15°, and -15° for each of the flap settings and a few tests were made with the tab deflected $\pm 10^\circ$, $\pm 20^\circ$, and $\pm 30^\circ$. The airfoil was tested with the gap at the flap nose sealed and also with gaps of 0.1, 0.5, and 1.0 percent of the airfoil chord. Lift, drag, and pitching moments of the airfoil and the hinge moments of the flap and the tab were measured. For each flap and tab setting, force tests were made throughout the angle-of-attack range from negative stall to positive stall at 2° increments of angle of attack.

RESULTS AND DISCUSSION

Symbols

The coefficients and the symbols used in this paper are defined as follows:

c_l airfoil section lift coefficient (l/qc)

c_{d_o} airfoil section profile-drag coefficient (d_o/qc)

c_m airfoil section pitching-moment coefficient (m/qc^2)

c_{h_f} flap section hinge-moment coefficient (h_f/qc_f^2)

c_{h_t} tab section hinge-moment coefficient (h_t/qc_t^2)

where

l airfoil section lift

d_o' airfoil section profile drag

m airfoil section pitching moment about quarter-chord point of airfoil

h_f flap section hinge moment

h_t tab section hinge moment

c chord of basic airfoil with flap and tab neutral

c_f flap chord

c_t tab chord

q dynamic pressure

and

α_o angle of attack for airfoil of infinite aspect ratio

δ_f flap deflection with respect to airfoil

δ_t tab deflection with respect to flap

Precision

The accuracy of the data is indicated by the deviation from zero of lift and moment coefficients at zero angle of attack. The maximum error in effective angle of attack at zero lift appears to be about $\pm 0.2^\circ$. Flap deflections were set to within $\pm 0.2^\circ$. Tunnel corrections, experimentally determined in the 4- by 6-foot vertical tunnel, were applied to lift only. The hinge moments, therefore, are probably slightly higher than would be obtained in free flight, but the values presented are considered to be conservative. The increments of drag should be reasonably independent of tunnel effect, although the absolute value is subject to an unknown correction. Inaccuracies in the section data presented are thought to be negligible relative to inaccuracies that will be incurred in the application of the data to practical installations.

L-377

Lift

In general, at any angle of attack and flap deflection, except when both the angle of attack and the flap deflection are zero, the lift increases as the gap is reduced (figs. 2, 3, and 4). With the flap deflected, the presence of a gap appears to have more effect upon the shift of angle of attack of zero lift than does the magnitude of the gap. Although the decrements of lift are directly proportional to the size of the gap, the variation is not linear and the rate of change of decrement becomes less as the gap is increased.

The slope of the lift curve $\partial c_l/\partial \alpha_o$ increases as the gap is reduced and is greater for 0° than for 10° flap deflection. With the flap neutral, the curve is linear to within 1° or 2° of the airfoil stall; whereas, with the flap deflected 10°, the curve is linear over only a small angle-of-attack range after which the slope is reduced, indicating separation of flow over the airfoil. This lift curve is of the same general shape as that of a highly cambered airfoil, such as the NACA 6709. At 20° flap deflection, the curve is linear for a small range of angles of attack, dependent upon the gap size, and then assumes a sharp break as the flap stalls. Beyond the flap stall, the curve becomes more gradual, indicating that separation is continuing to build up over the airfoil proper as the lift increases until the airfoil finally stalls. At 30° flap deflection, the flap is stalled throughout the entire angle-of-attack range and the lift curve is nonlinear.

Reducing the gap delays separation and the stall of the flap. Apparently the presence of a gap allows a flow of air over the nose of the flap, which tends to reduce the pressure peaks that exist at the hinge axis when the gap is sealed (reference 2). These peaks produce a pressure gradient in front of the hinge axis that is favorable in retarding separation and also an adverse pressure gradient behind the axis that precipitates the stalling of the flap. Since flaps stall earlier as the gap is increased and the effect of the gap appears to be to reduce the pressure peaks, it is probable that the absence of a favorable pressure gradient ahead of the hinge axis causes flaps having a gap at the nose to stall earlier than those having a sealed gap.

Figure 2(c) indicates how the size of gap affects the stall. At a flap deflection of 20°, the flap with sealed gap stalls at a c_l of about 0.6. With a 0.001c gap the flap stall occurs at about $c_l = 0.2$, but with the 0.005c and 0.010c gaps the flap is stalled throughout the entire angle-of-attack range.

The variation of lift coefficient with flap deflection at a high positive angle of attack gives a curve that is nonlinear for all gaps, the smallest gap giving highest lift at all flap deflections. An angle of attack of 8° is a typical high angle of attack for a wing of infinite span; whereas, for a wing of aspect ratio 3, the same lift will occur at nearly twice this angle.

At a small angle of attack ($\alpha_0 = 0^{\circ}$), the lift varies linearly with flap deflection only to about 5° for all gaps. With large gaps separation occurs early and continuously, causing large losses in lift as indicated by a gradual rounding of the curve. As the gap is reduced, the flap stall becomes more pronounced and greater lift is developed at a given flap deflection.

At a large negative angle of attack ($\alpha_0 = -8^{\circ}$ for a wing of infinite aspect ratio) and with sealed and 0.001c gaps, the variation of lift coefficient is linear with flap deflection up to $\delta_f = 20^{\circ}$, and the flap stall is pronounced. For the larger gaps, however, the variation is linear only to about $\delta_f = 15^{\circ}$ because separation occurs earlier and more gradually, making the flap stall more obscure. These results are in agreement with previous tests, such as those reported in reference 1.

Increasing the flap nose gap precipitates separation over the flap with the tab both neutral and deflected (fig. 5). A tab deflected in opposition to the flap causes smaller reductions in lift as the flap gap is increased. On the other hand, a tab deflected with the flap produces greater increments in lift as the gap is increased, although this effect is not pronounced except at small angles of attack (fig. 5(b)). The magnitude of these effects increases with tab deflection. At large flap and small tab deflections, separation phenomena cause a departure from the above-mentioned tendencies when, with a large gap, a flap may be stalled, but, with a small one, it would be unstalled.

L-377

Hence these tests indicate that a tab is more effective as a trimming device when used on a flap having a large gap at the nose than when used on a flap having a small or sealed gap. It does not follow, however, that the over-all effectiveness of flap and tab is greater with a gap at the flap nose. Figures 3 and 4 show that small or sealed gaps are desirable even with the tab deflected.

Hinge Moment of Flaps

Curves showing the variation of flap-hinge moment coefficient as a function of lift coefficient at constant flap deflection (figs. 2, 3, and 4) indicate that, at a given lift coefficient, the hinge-moment coefficient of the flap generally increases slightly as the gap is reduced. At high flap deflections, the early separation of flow on flaps with large gaps reverses the order of the curves when the flap with a large gap is stalled; whereas, at the same angle of attack and flap deflection, the flap with a small gap may not be stalled.

Curves showing the variation of flap section hinge-moment coefficient as a function of lift coefficient at constant angle of attack (fig. 6) indicate that the hinge-moment coefficient decreases as the gap is reduced. This result, which is independent of tab deflection, is due to the fact that a given lift is obtained at lower flap deflections as the gap is reduced. At large negative angles of attack (fig. 6(c)), any advantages gained by sealing the gap are slight until a flap deflection sufficient to give positive lift is reached. The curves of figure 6 clearly indicate the reductions in stick force to be expected by sealing the gap because the hinge-moment coefficient is proportional to the stick force for any control system of constant mechanical advantage.

Pitching Moment

With the flap and the tab neutral and the flap gap sealed, the rate of change of pitching-moment coefficient with lift coefficient $(\partial c_m/\partial c_l)_{\delta_f,\delta_t}$ is 0.010 (fig. 2). This slope places the aerodynamic center at the 24-percent-chord point, which agrees with tests of reference 7. As the gap is increased, the pitching-moment generally

decreases and the curves tend to steepen slightly, indicating a forward shift of the aerodynamic center.

As the flap is deflected, the increments of pitching-moment coefficient caused by gap become greater and the curves (figs. 2, 3, and 4) become nonlinear probably because of separation phenomena. This effect increases with lift coefficient.

Drag

At unstalled attitudes of the flap, the drag increses with increasing gap, and the increments caused by gap become greater as the lift increases positively (figs. 2, 3, and 4). Because of a relatively large unknown tunnel correction, the drag coefficients cannot be considered as absolute; however, the relative values should be independant of tunnel effects.

Hinge Moment of Tab

The air gap at the nose of the tab was not varied but was held constant at 0.001c for all tests. Figures 2, 3, and 4 indicate that the tab hinge moment generally increases as the gap at the flap nose is increased. This effect is more pronounced at high flap deflections.

Parameters

In general, the order of magnitude of the increments in the parameters (reference 5) caused by changes in gap are of the same order of magnitude as the limits of accuracy in determining the values of the parameters. This fact may be caused by precision errors already discussed or by actual nonlinearity of the various curves because of separation phenomena. Only the general trend, therefore, rather than the magnitude of the variation of the various parameters with gap is indicated below. As the gap at the nose of the flap is decreased, the parameters

$\left(\frac{\partial c_l}{\partial \alpha_0}\right)_{\delta_f, \delta_t}$, $\left(\frac{\partial c_l}{\partial \delta_f}\right)_{\alpha_0 \delta_t}$, and $\left(\frac{\partial \alpha_0}{\partial \delta_f}\right)_{c_l, \delta_t}$ increase; $\left(\frac{\partial c_m}{\partial c_l}\right)_{\delta_f, \delta_t}$,

$$\left(\frac{\partial c_m}{\partial \delta_f}\right)_{c_l,\delta_t}, \left(\frac{\partial c_{h_f}}{\partial \delta_f}\right)_{c_l,\delta_t}, \text{ and } \left(\frac{\partial c_{h_f}}{\partial \delta_t}\right)_{c_l,\delta_f} \text{ decrease;}$$

$$\text{and } \left(\frac{\partial c_{h_f}}{\partial c_l}\right)_{\delta_f,\delta_t}$$

and the tab parameters, not previously mentioned, remain about the same.

The plain flap with the largest gap (0.010c) is only about 76 percent as effective in producing lift as the flap with the sealed gap (fig. 7).

CONCLUDING REMARKS

The results indicate that an airfoil having a sealed gap at the flap nose required less stick force at a given lift and angle of attack than an airfoil having any size gap within the range tested. Sealing the gap also increased the control effectiveness, delayed separation over the flap, decreased the drag at most values of lift, and slightly reduced the effectiveness of the tab. Where maximum flap effectiveness and minimum stick forces are primary considerations in designing a plain flap control surface, the gap at the flap nose should be sealed.

Too much reliance should not be placed in the use of parameters to obtain characteristics of flapped airfoils with gaps because the gap precipitates separation, causing an early departure from the linear relationships assumed to exist between the variables.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCES

1. Goett, Harry J., and Reeder, J. P.: Effects of Elevator Nose Shape, Gap, Balance, and Tabs on the Aerodynamic Characteristics of a Horizontal Tail Surface. Rep. No. 675, NACA, 1939.

2. Ames, Milton B., Jr., and Sears, Richard I.: Pressure-Distribution Investigation of an N.A.C.A. 0009 Airfoil with a 30-Percent-Chord Plain Flap and Three Tabs. T.N. No. 759, NACA, 1940.

3. Street, William G., and Ames, Milton B., Jr.: Pressure-Distribution Investigation of an N.A.C.A. 0009 Airfoil with a 50-Percent-Chord Plain Flap and Three Tabs. T.N. No. 734, NACA, 1939.

4. Ames, Milton B., Jr., and Sears, Richard I.: Pressure-Distribution Investigation of an N.A.C.A. 0009 Airfoil with an 80-Percent-Chord Plain Flap and Three Tabs. T.N. No. 761, NACA, 1940.

5. Ames, Milton B., Jr., and Sears, Richard I.: Determination of Control-Surface Characteristics from NACA Plain-Flap and Tab Data. T.N. No. 796, NACA, 1941.

6. Wenzinger, Carl J., and Harris, Thomas A.: The Vertical Wind Tunnel of the National Advisory Committee for Aeronautics. Rep. No. 387, NACA, 1931.

7. Jacobs, Eastman N., Pinkerton, Robert M., and Greenberg, Harry: Tests of Related Forward-Camber Airfoils in the Variable-Density Wind Tunnel. Rep. No. 610, NACA, 1937.

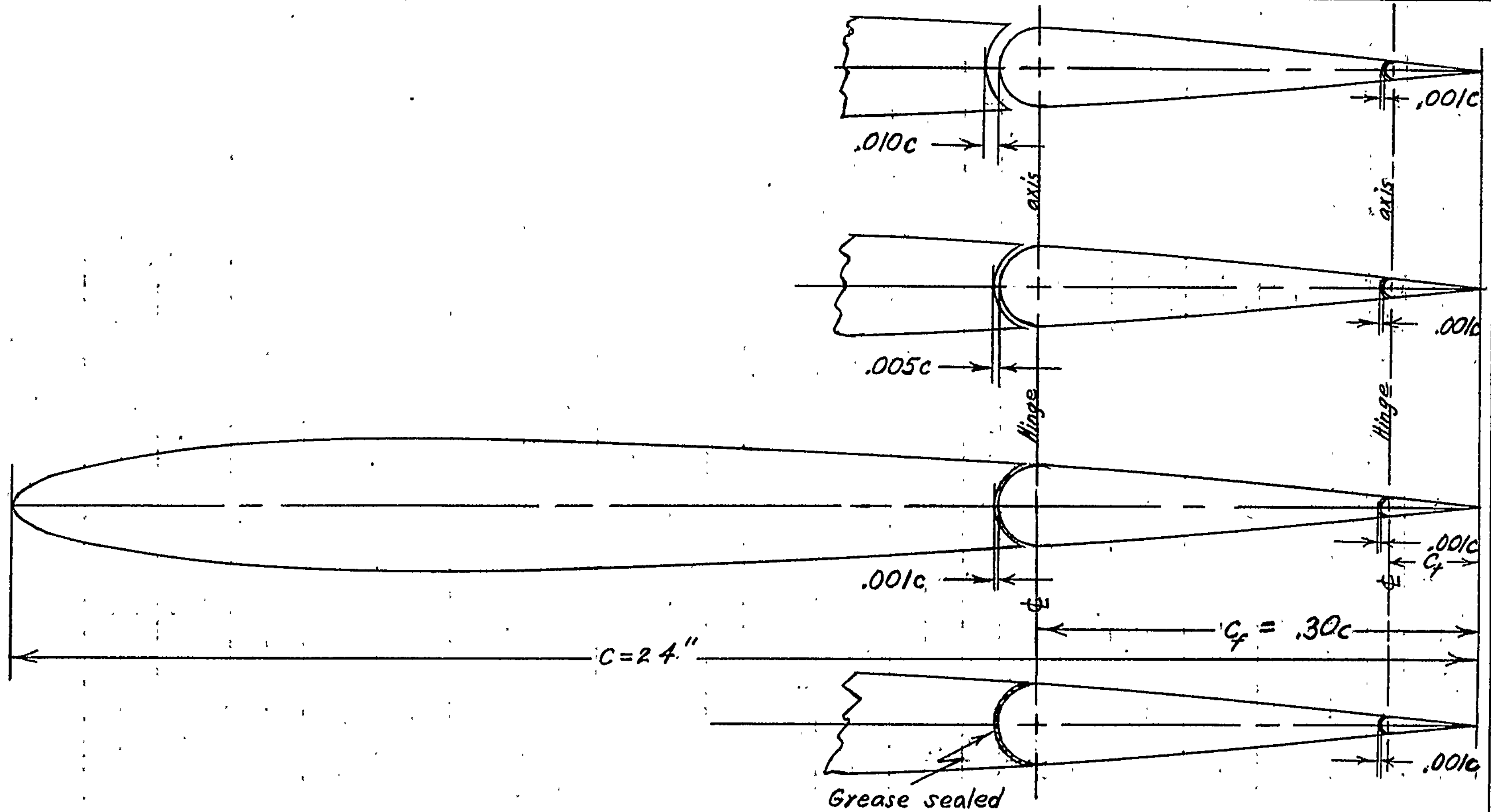
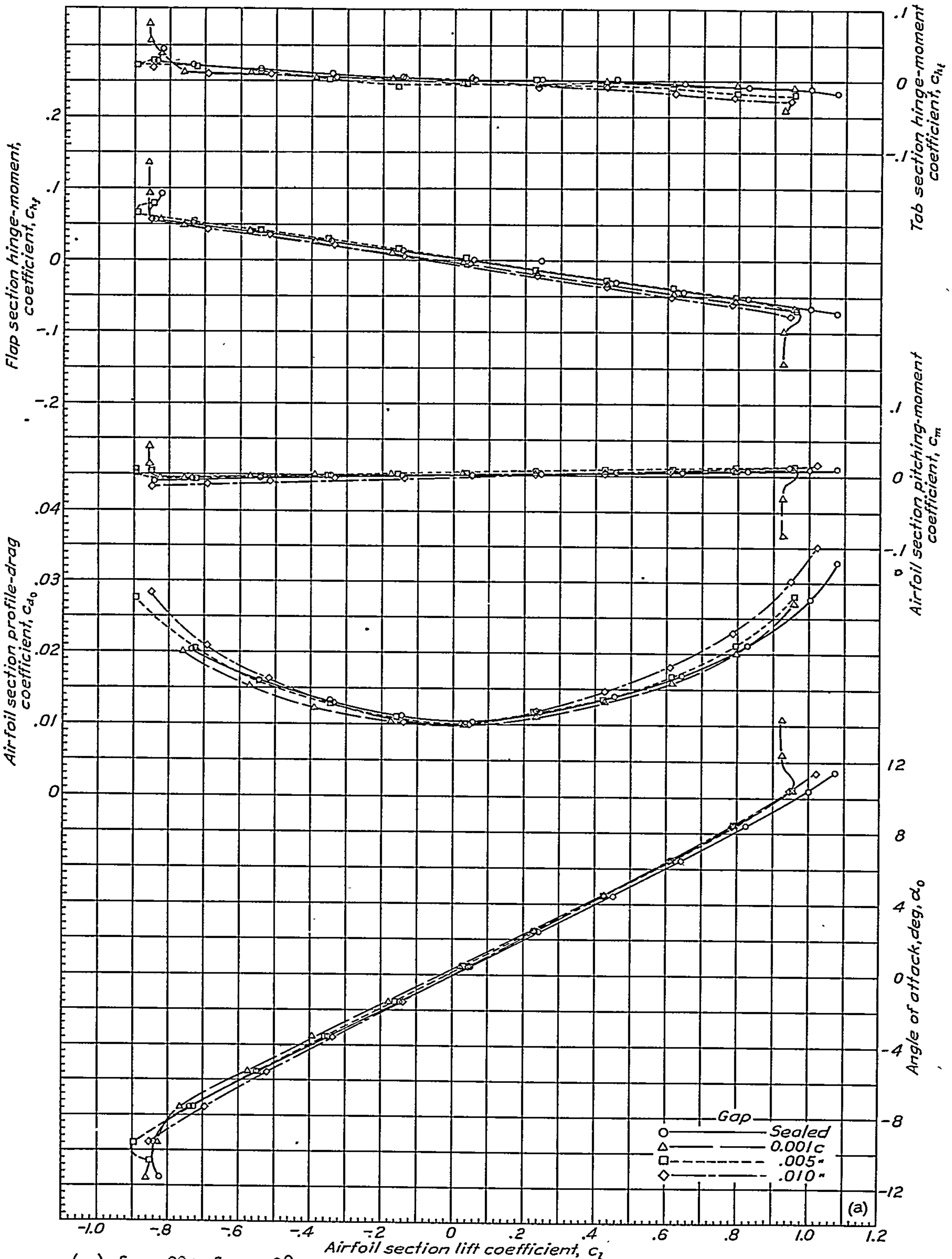
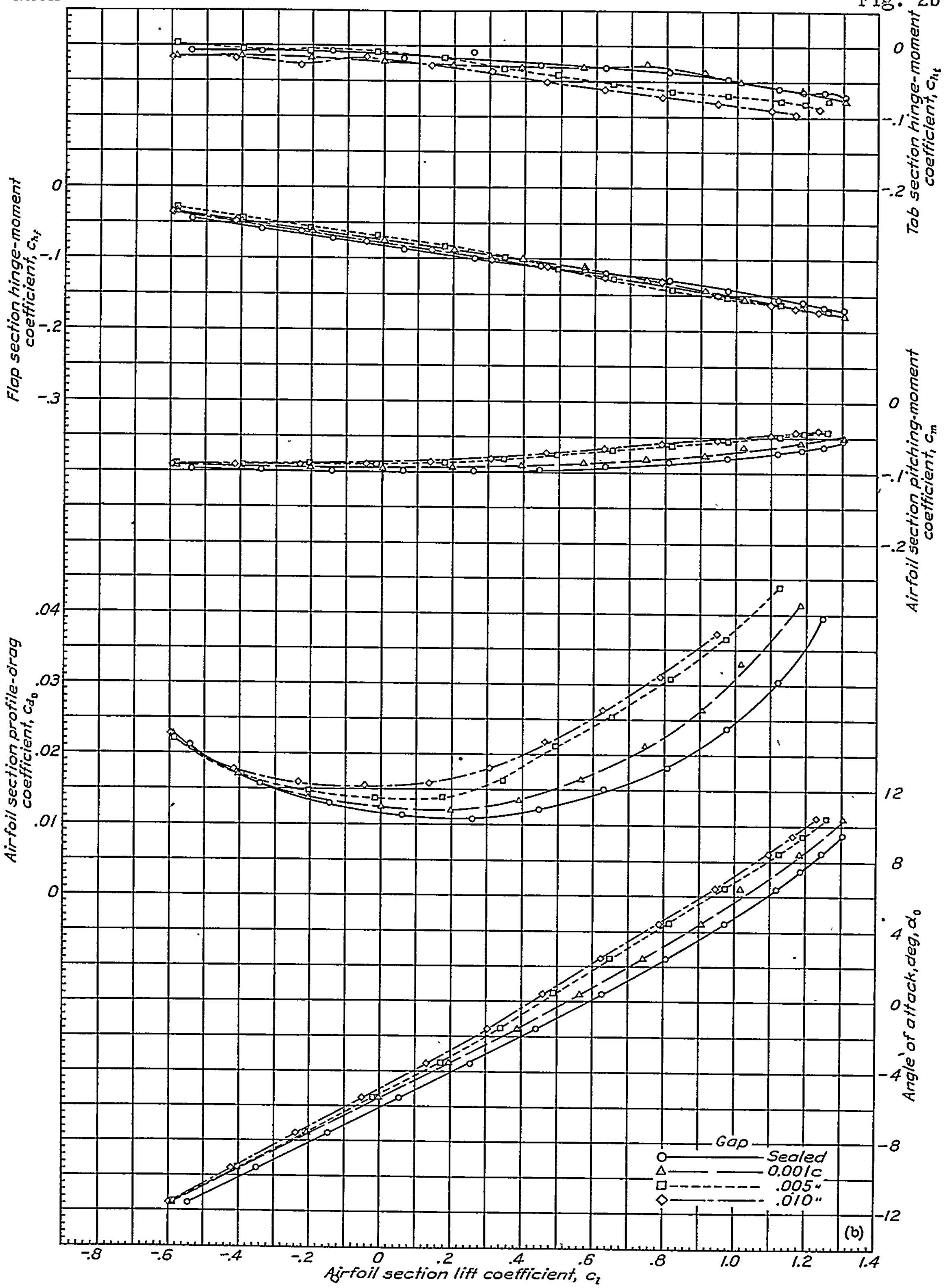


Figure 1.— Profile of model. NACA 0009 airfoil with a 0.30c plain flap and a 0.20c_f plain tab and having various gaps at the flap nose.



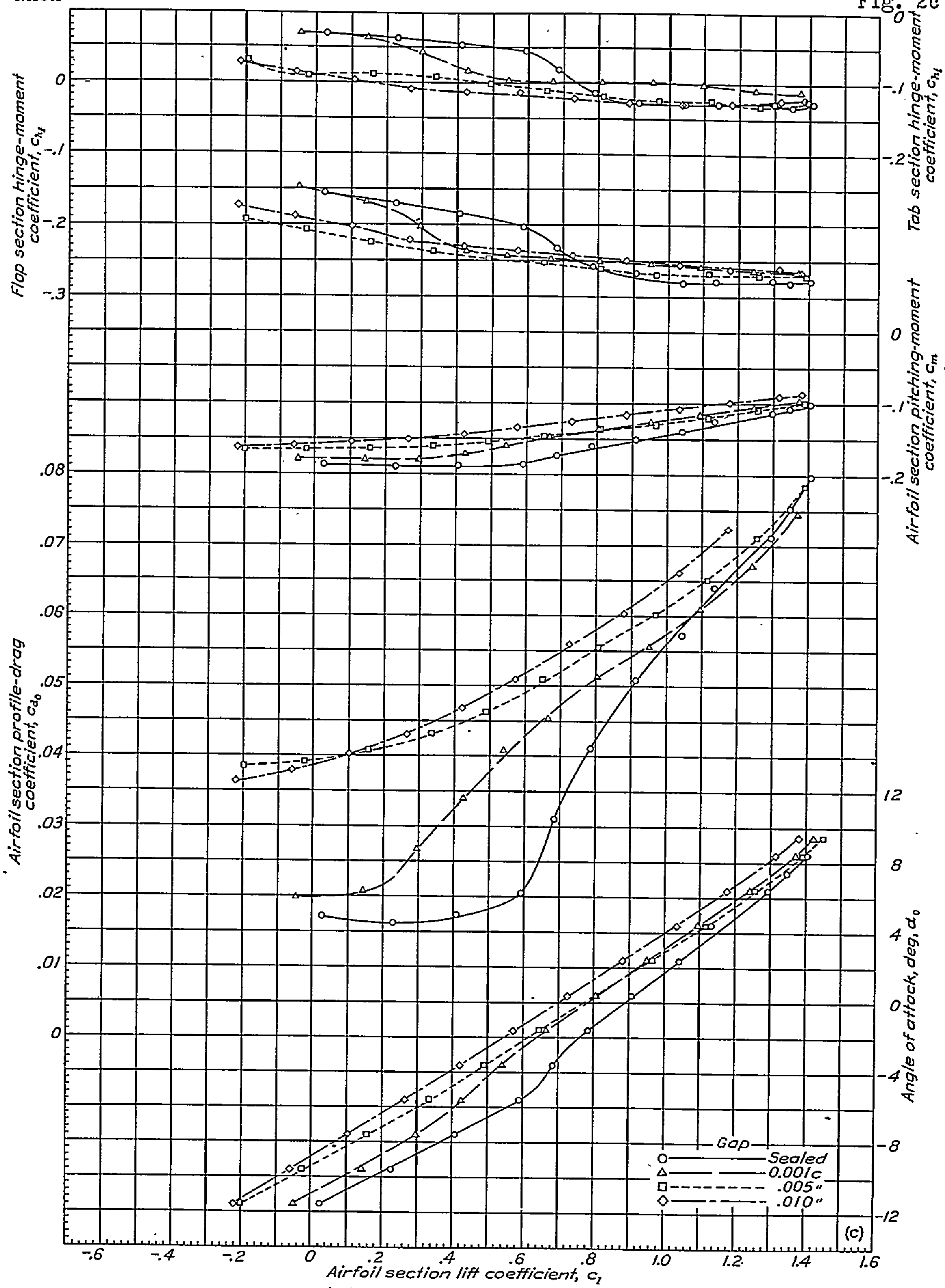
(a) $\delta_f = 0°$; $\delta_t = 0°$.

Figure 2 a to d.- Aerodynamic section characteristics of an NACA 0009 airfoil having a 0.30c plain flap with various gaps and a 0.20c_f plain tab. Flap deflected to several angles and tab deflected 0°.



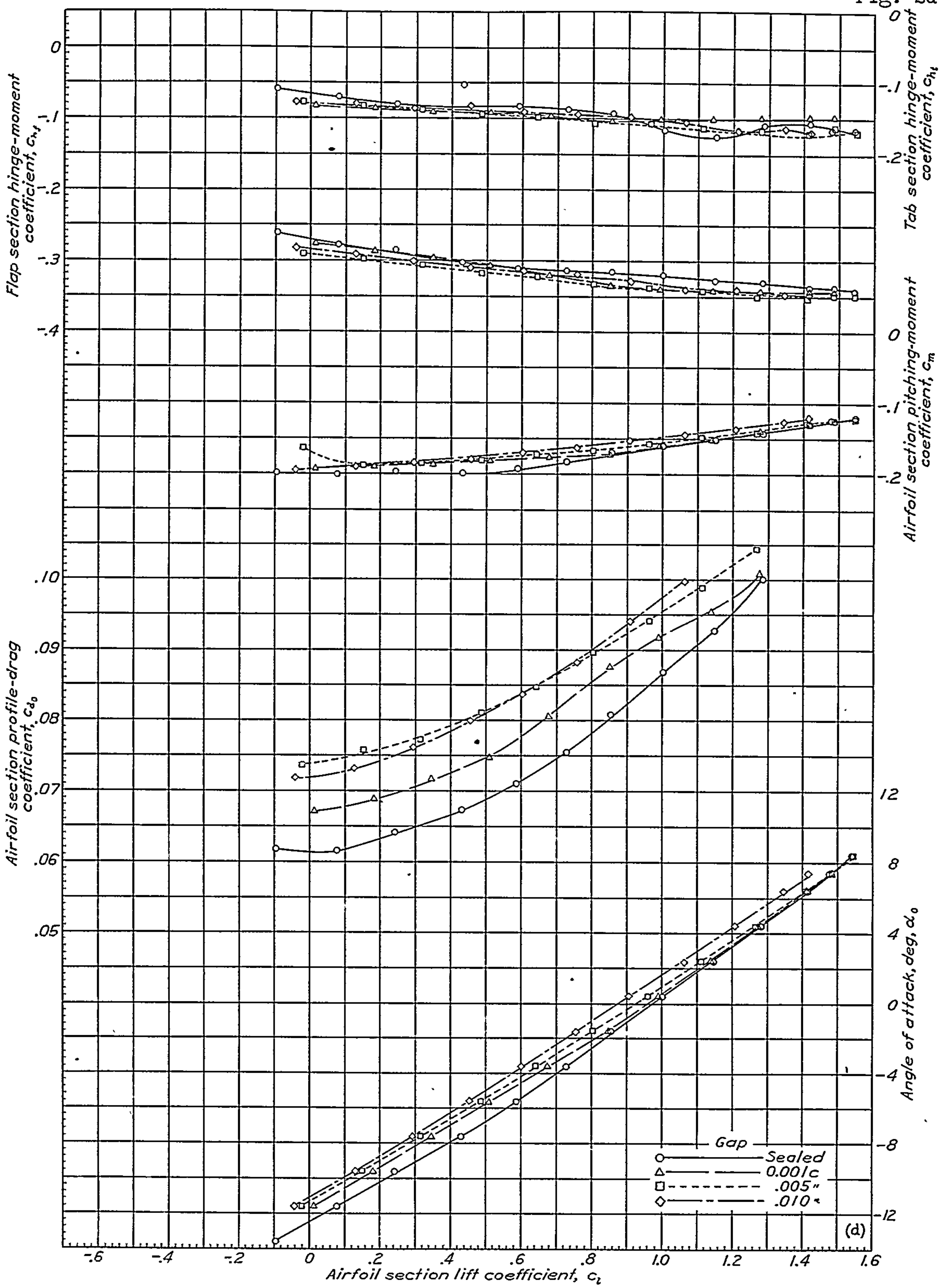
(b) $\delta_f = 10^\circ$; $\delta_t = 0^\circ$.

Figure 2.- Continued.



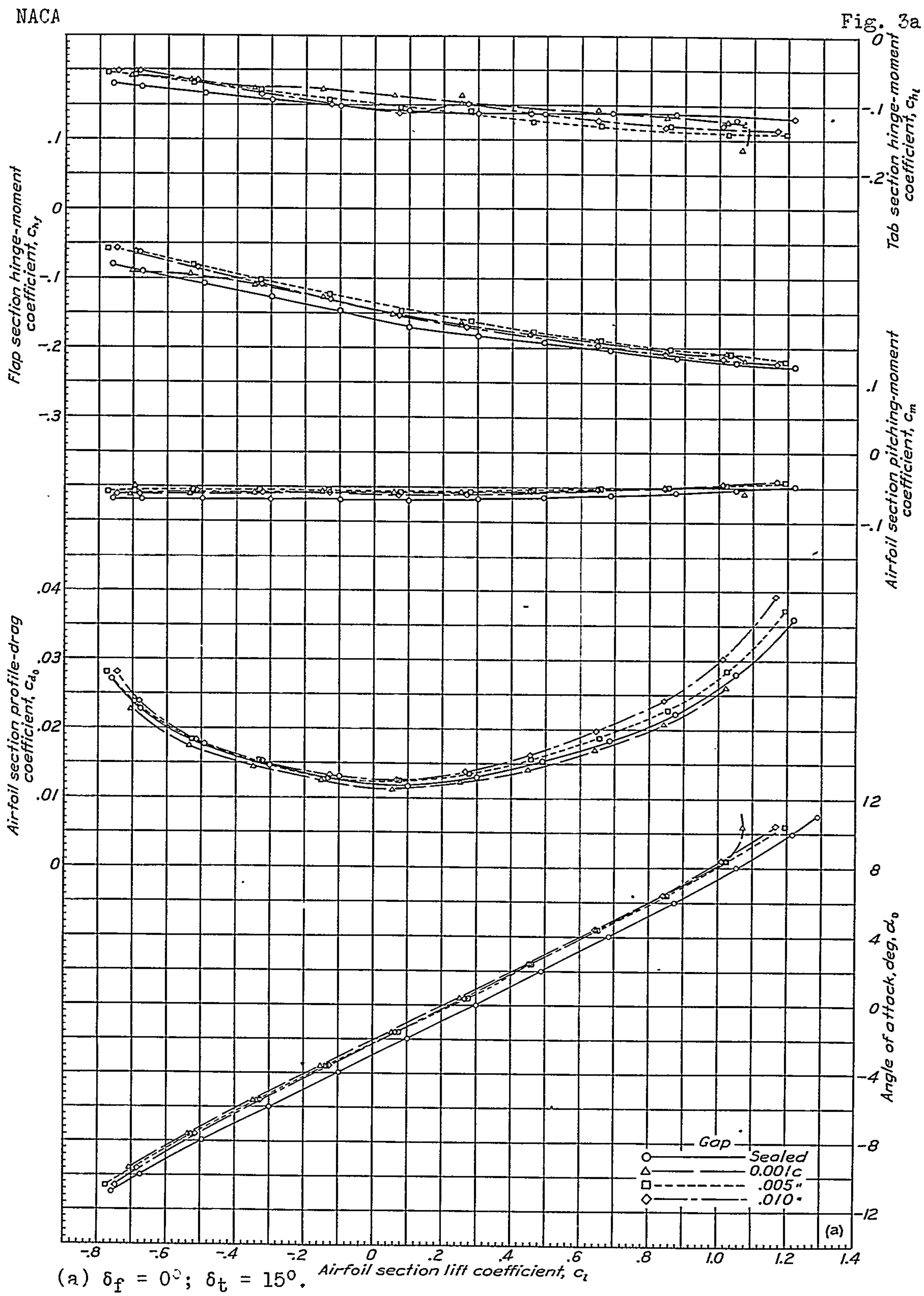
(c) $\delta_f = 20^o$; $\delta_t = 0^o$.

Figure 2.- Continued.



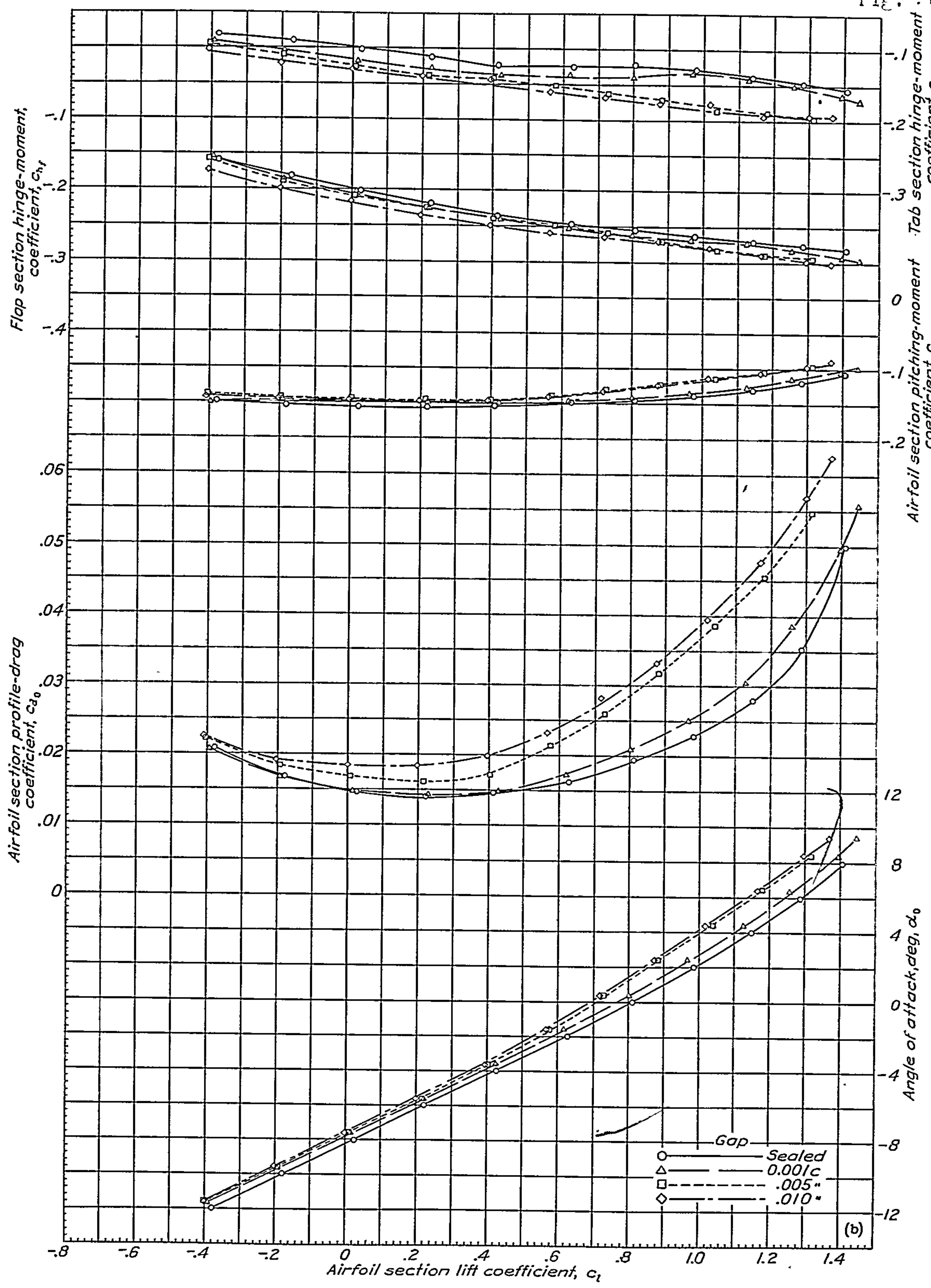
(d) $\delta_f = 30°$; $\delta_t = 0°$.

Figure 2.- Concluded.



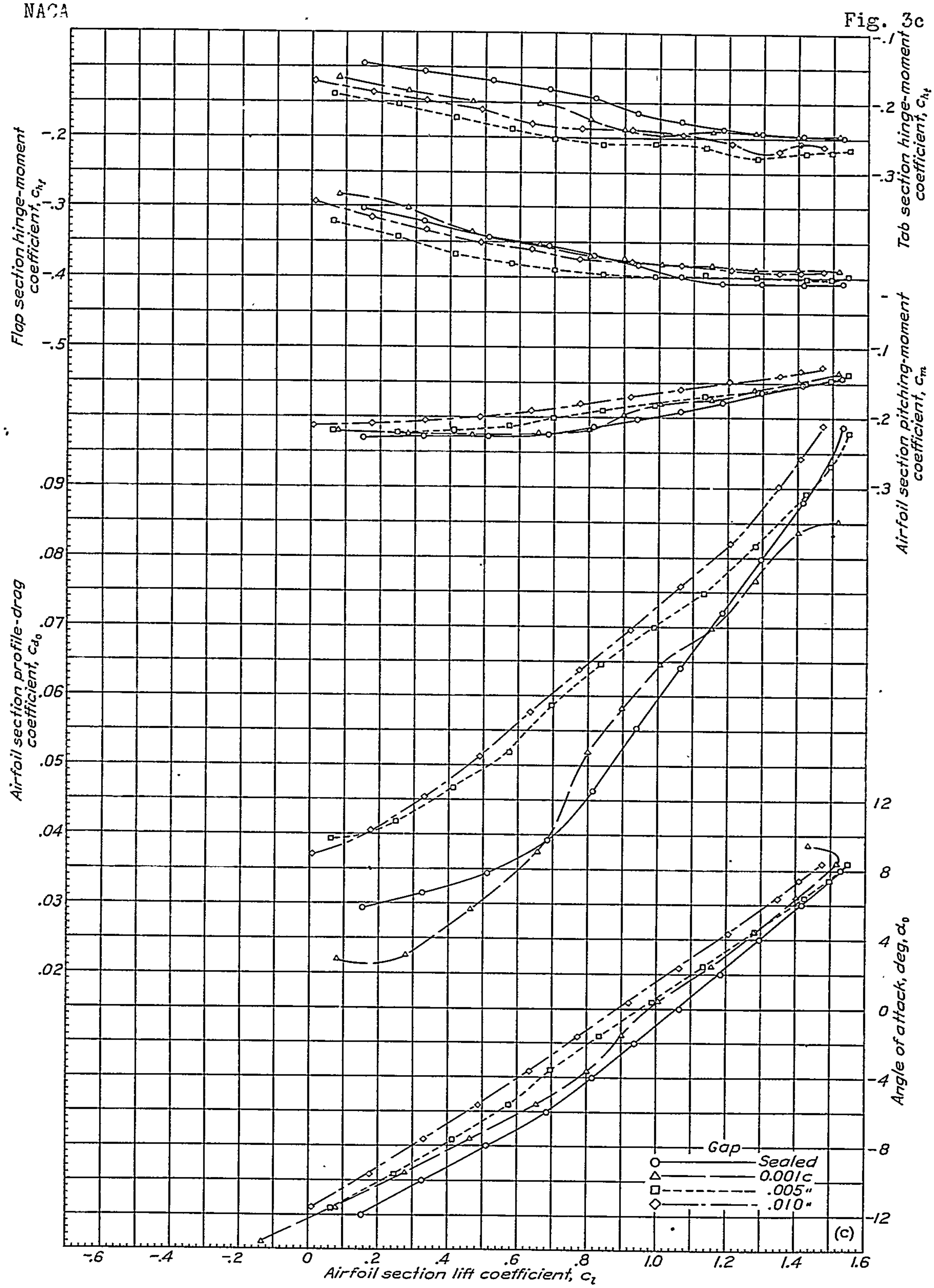
(a) $\delta_f = 0°$; $\delta_t = 15°$.

Figure 3 a to d.- Aerodynamic section characteristics of an NACA 0009 airfoil having a 0.30c plain flap with various gaps and a 0.20c plain tab. Flap deflected to several angles and tab deflected 15°.



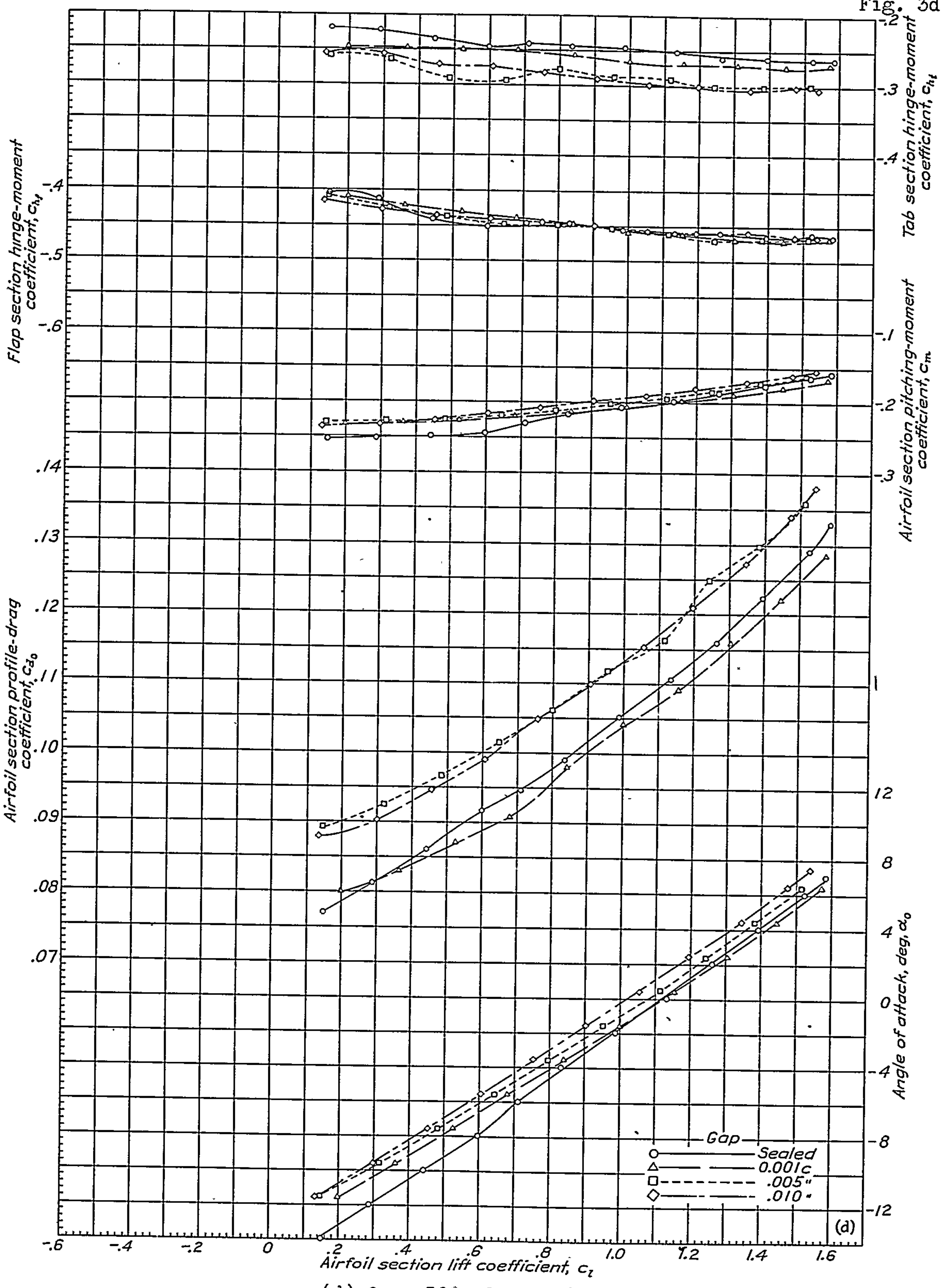
(b) $\delta_f = 10^\circ$; $\delta_t = 15^\circ$.

Figure 3.- Continued.



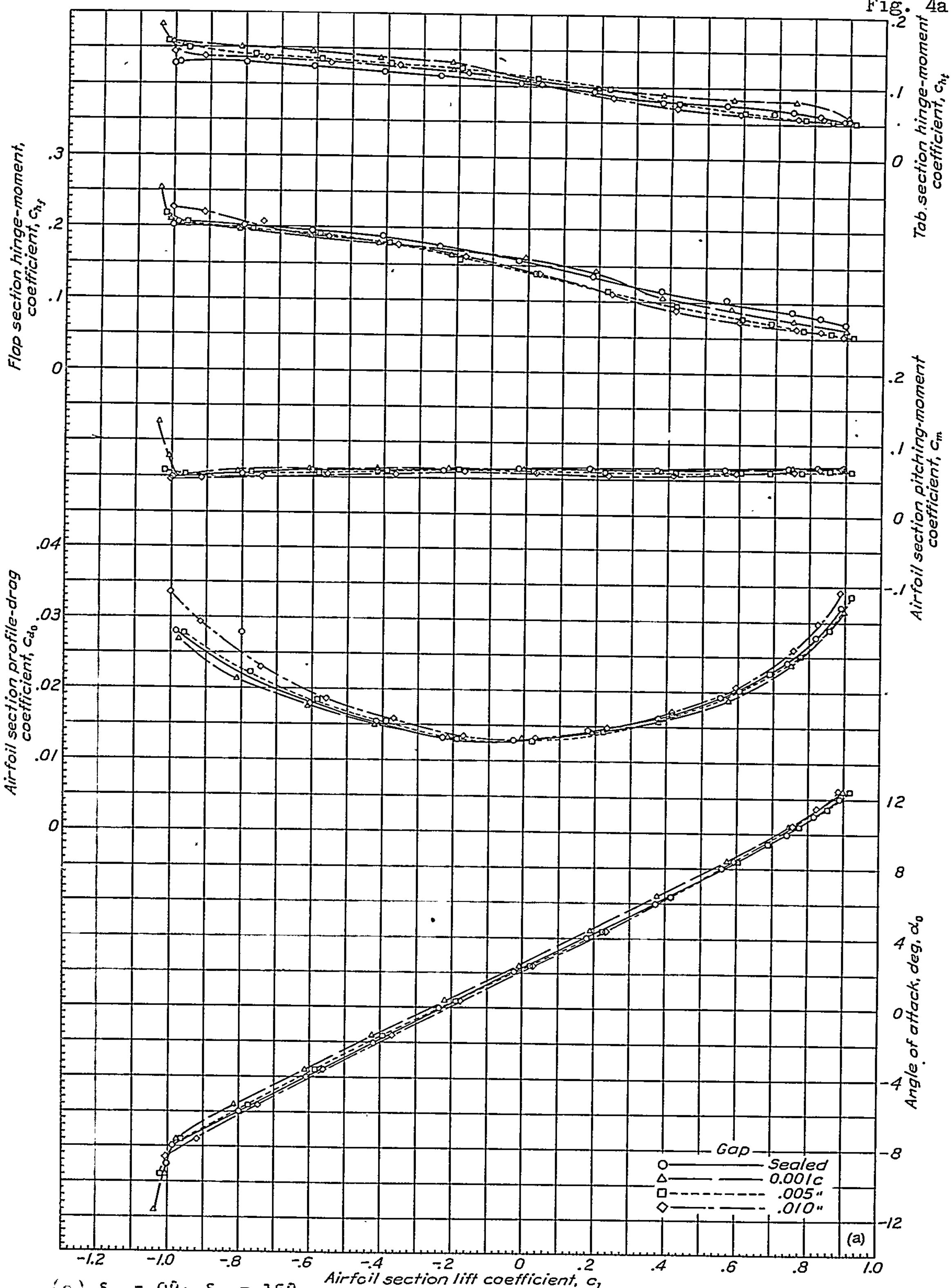
(c) $\delta_f = 20^\circ$; $\delta_t = 15^\circ$.
Figure 3.- Continued.

L-377



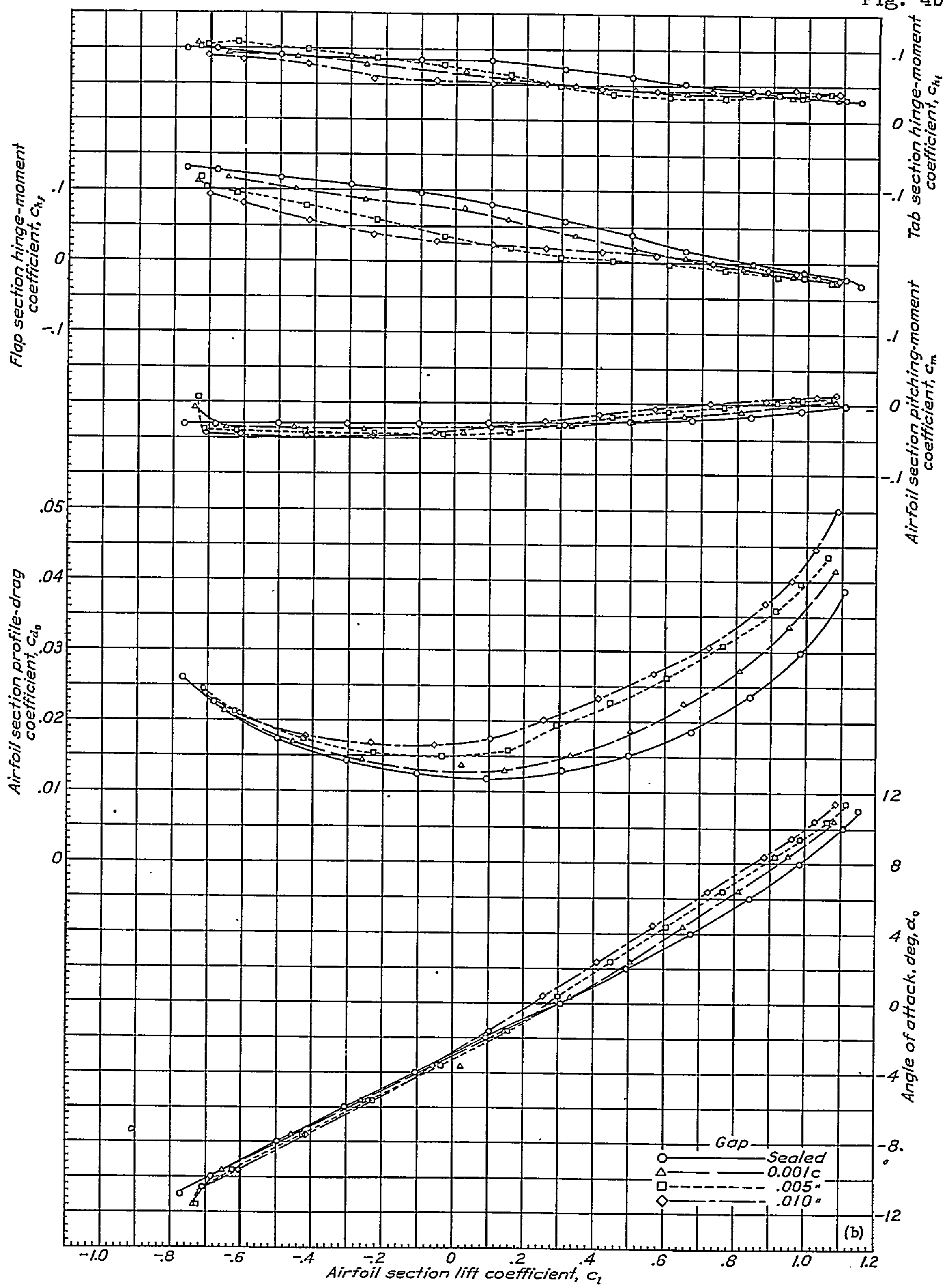
(d) $\delta_f = 30^\circ$; $\delta_t = 15^\circ$.

Figure 3.- Concluded.



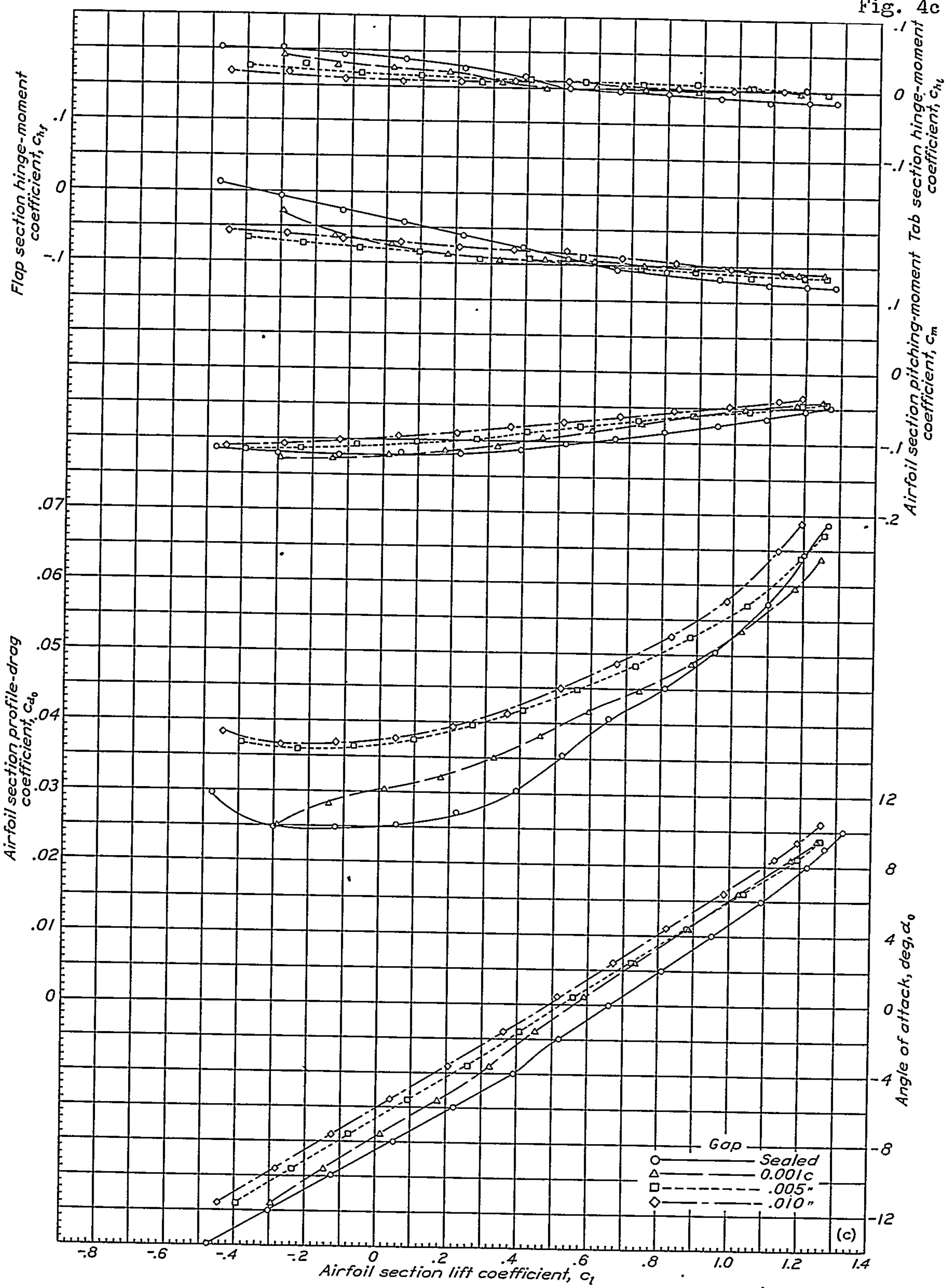
(a) $\delta_f = 0°$; $\delta_t = -15°$.

Figure 4 a to d.- Aerodynamic section characteristics of an NACA 0009 airfoil having a 0.30c plain flap with various gaps and a 0.20c_f plain tab. Flap deflected to several angles and tab deflected -15°.



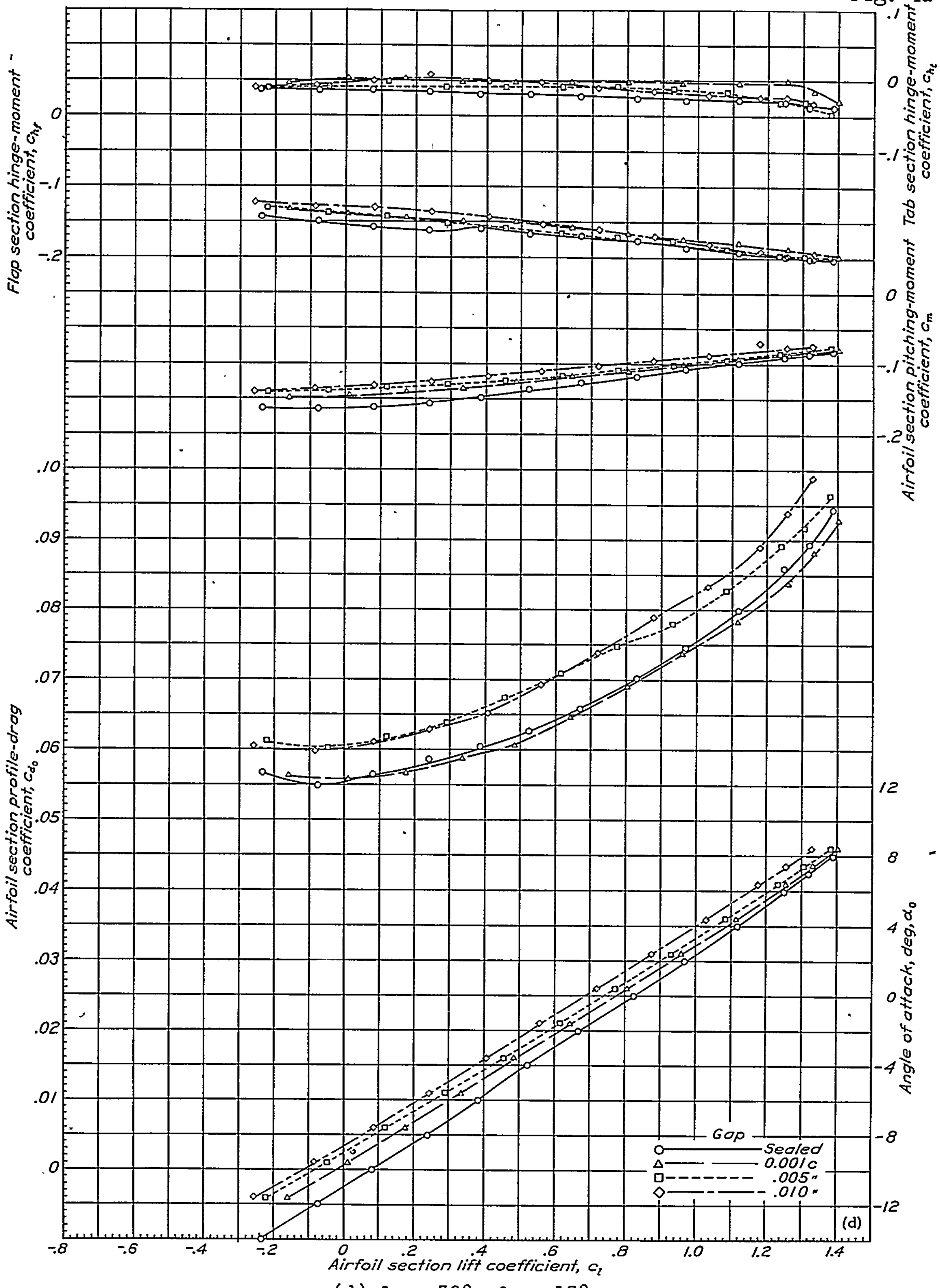
(b) $\delta_f = 10^\circ$; $\delta_t = -15^\circ$.

Figure 4.- Continued.



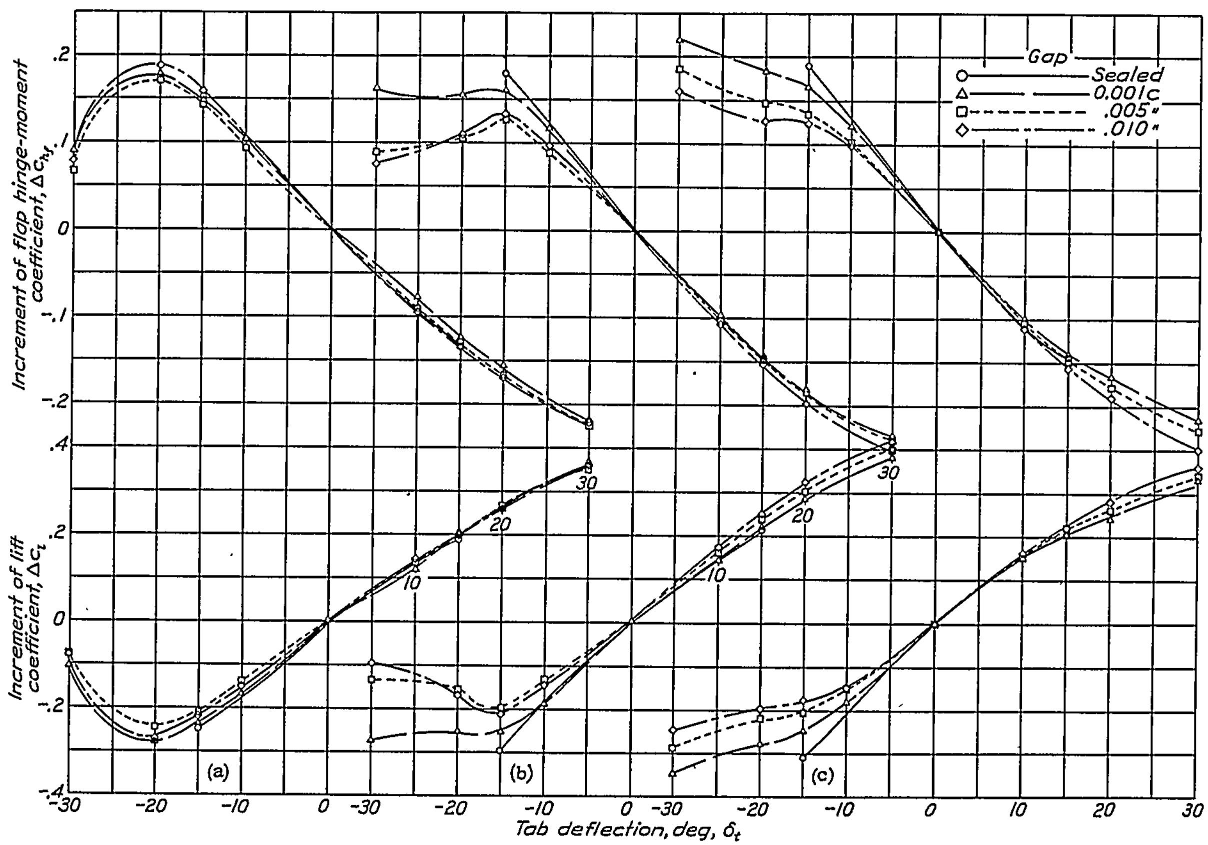
(c) $\delta_f = 20^\circ$; $\delta_t = -15^\circ$.

Figure 4.- Continued.



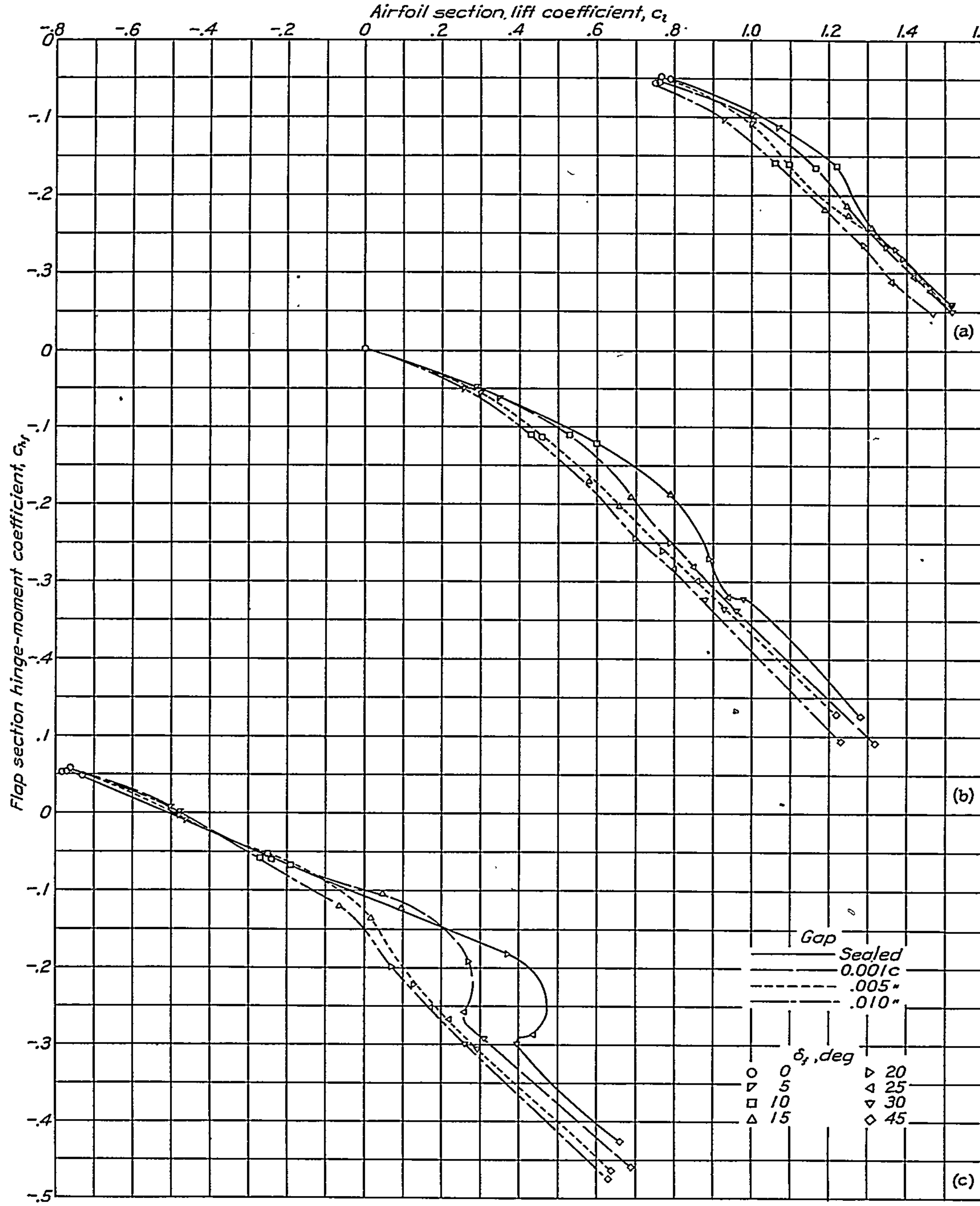
(d) $\delta_f = 30^\circ$; $\delta_t = -15^\circ$.

Figure 4.- Concluded.



(a) $\alpha_0 = 8^\circ$, $\delta_f = 10^\circ$. (b) $\alpha_0 = 0^\circ$, $\delta_f = 10^\circ$. (c) $\alpha_0 = -8^\circ$, $\delta_f = 10^\circ$.

Figure 5.- Increments of airfoil section lift coefficient and flap section hinge-moment coefficient with tab deflection at several angles of attack and for various gaps.



(a) $\alpha_0 = 8^\circ$; $\delta_t = 0^\circ$. (b) $\alpha_0 = 0^\circ$; $\delta_t = 0^\circ$. (c) $\alpha_0 = -8^\circ$; $\delta_t = 0^\circ$.

Figure 6.- Variation of flap section hinge-moment coefficient with airfoil section lift coefficient at several angles of attack and tab deflections and for various gaps.

L-377

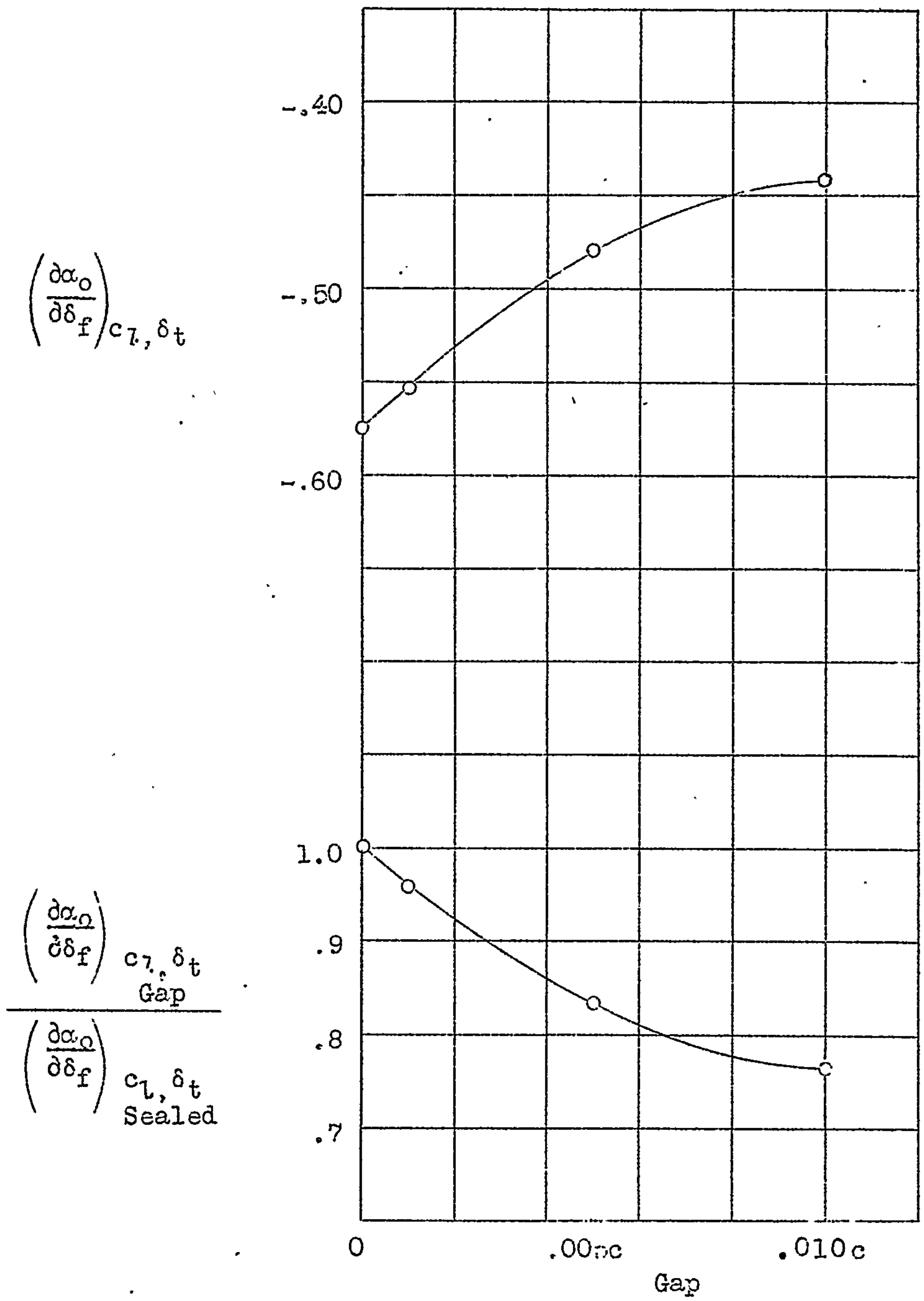


Figure 7.- Variation of parameter $\left(\frac{\partial\alpha_o}{\partial\delta_f}\right)_{c_l,\delta_t}$ with flap gap.